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CHANNEL ESTIMATION USING PILOT SYMBOLS

5 Field of the invention

The present invention relates to telecommunication systems and more specifically to techniques for estimating the transfer function of a transmission channel.

10 Description of the related art

W-CDMA (Wideband - Code Division Multiple Access) is a well known technique used in mobile radio communication systems i.a. by virtue of its high spectral efficiency as compared to other multiple 15 access techniques.

In a W-CDMA system, a base station is associated with a respective scrambling code in order to distinguish it from other different base stations.

As schematically shown in figure 1, in such an 20 arrangement a base station 1 generates a radio signal that is transmitted through a propagation channel C and reaches a remote receiving mobile terminal 2. Specifically, in figure 1, a mobile terminal receiver 25 front end is shown including a RF receiver 2a, an analog-to-digital converter 2b and a digital front end 2c from which the received signal is sent to a so-called "rake" receiver better detailed in figure 2.

Each mobile terminal is associated to a different 30 orthogonal spreading code. As these codes are orthogonal, a given remote terminal is able to separate its own data stream from those transmitted to the other active users. Before being transmitted from the base station 1 over the propagation channel, the signal is subject to scrambling and spreading by resorting to the

codes mentioned in the foregoing.

A further distinction within CDMA systems is between those systems that use different frequencies for transmission and reception (in Frequency Division Duplex or FDD mode) and those systems that use a common frequency for both the transmission and reception but separate the signals in the time domain (in Time Division Duplex or TDD mode).

In the specific case of those networks operating according to the Universal Mobile Telecommunications System (UMTS) standard, the dispersion of the transmitted signal energy over time due to the propagation channel can be usefully exploited, by using the properties of the spreading codes, in order to separate the different received signal replicas and to recombine them constructively. As the amplitudes of the different replicas are statistically independent, such a constructive recombination increases the probability that the received signal is above the minimum level for a correct reception. This property is usually referred to as path diversity or time diversity and can be exploited by means of a "rake" receiver.

As shown in figure 2, a mobile terminal rake receiver 3 can be thought as a modular device including a number of independent receiving units, named "fingers" 4, each of which is "tuned" to a different received signal replica as provided by a code generator 4a. Each finger 4 in the receiver performs - by means of different processing blocks - several operations on the received signal (timing acquisition and tracking, channel estimation and compensation, frequency correction, de-scrambling, de-spreading, integration). In order to exploit path diversity, the symbol estimates at the output of the various fingers are

recombined in a block 5 according to a maximum ratio combining criterion.

Within the framework of CDMA techniques, and specifically with reference to the frequency division duplex (FDD) mode, various solutions have been devised in order to increase system capacity. Among these, coherent demodulation of the signal received by the radio mobile station or mobile terminal deserves being mentioned. Coherent demodulation is used in digital communication systems when optimum error performance is of paramount importance. When employing a coherent reception scheme, channel estimation is achieved making use of known pilot symbols that are transmitted along with the data symbols.

More in detail, a number of known solutions exists for estimating the propagation channel in the specific case of the base station simultaneously transmitting towards the mobile terminal both a pilot signal and a data signal containing a pilot field.

The pilot signal is totally comprised of known symbols and transmits the same information to all users, whilst the data signal is different from user to user and comprises only a dedicated pilot field, which is time-multiplexed with the data and is known to the receiver. Channel estimation consists in exploiting these known symbols, transmitted by the base station, in order to identify essentially the phase changes introduced on the data by the propagation channel.

The slot formats adopted for the data signal and for the pilot signal in the FDD mode of the UMTS "downlink" path are shown by way of example in figure 3 and figure 4a, 4b, respectively.

The pilot signal is made of ten pilot symbols per slot, whilst the data signal may have a variable number

of pilot symbols per slot depending on its spreading factor value.

When channel estimation is obtained by means of the pilot channel, the mobile terminal has knowledge of 5 all the transmitted pilot symbols. The mobile terminal exploits these known pilot symbols to estimate the correspondent phase changes due to the propagation channel. In such a way the channel can be estimated continuously over the entire slot.

10 Channel estimation can be achieved also by exploiting the data signal. Observation of the slot format of the data signal makes it clear that the channel coefficients can be estimated only in correspondence of the dedicated pilot field. A problem 15 thus arises due to the dedicated pilot symbols being transmitted only in a part of each slot. The remaining part of the slot is used for the transmission of other data so that it is not possible to estimate the channel coefficients continuously over the slot.

20 The pilot channel can be used to transmit common information to all the users within a cell, so its received power gradually decreases as the distance between the base station and the mobile terminal increases. On the contrary, the data signal is used to 25 transmit individual information to a specific user. The base station 1 controls the transmission power in order to guarantee that the information will be received with the same power level independently of the position of the mobile terminal 2 with respect to the base station 30 1.

Various arrangements are known in the art that are capable of performing channel estimation exploiting both a pilot signal and a data signal.

By way of example, reference can be made to the arrangement described in U.S. Patent application US2001/0043642 - schematically shown in figure 5. The arrangement in question includes devices 8a and 8b adopted to evaluate the power level of the two signals above, once basic finger operations 6 and 7 have been carried out. By comparing the respective power values calculated in the units 8a, 8b by means of a comparator 9, a selector unit 10 selects the pilot symbols with the highest power level and exploits only this signal for the channel estimation unit 11 to carry out the estimation task.

In this arrangement, the channel estimation unit operating on the pilot signal is likely to be used when the mobile terminal is close to the base station, whilst the channel estimation unit working on the data signal is likely to be used when the mobile terminal is far away from the base station. In that way essentially the same reception characteristics can be obtained no matter where the mobile terminal is positioned.

Applicants remark that the arrangement in question requests that both estimation units are implemented together with a power calculating device able to convert the two signals in the corresponding power values in order to choose the largest one by using the comparator. Even though using only one of the two estimation units at a time, the total complexity of the arrangement is made up of the sum of the complexities of both devices.

Another arrangement using both a pilot signal and a data signal is disclosed in U.S. Patent application US 2002/0186677. In that arrangement, shown by way of reference in figure 6, the apparatus includes a pilot filter 12 able to generate channel estimates from the pilot signal and a circuit 13 for reconstructing the

data information bits. A predictive channel estimation circuit 14 generates predictive channel estimates from the reconstructed data signal, which has been reconstructed exploiting the circuit 13.

5 These estimates are used together with those obtained from the pilot signal to demodulate the received data via a module 15, thus achieving a higher accuracy than in the case the estimates obtained from the pilot signal alone are used.

10 In this arrangement the combination of the pilot signal channel estimates with the reconstructed data signal channel estimates is carried out according to quality indicators of the reconstructed data signal information bits. The predictive channel estimator, 15 generates the predictive channel estimates from the combined pilot signal channel estimates and reconstructed data signal channel estimates. This solution achieves a higher degree of accuracy in comparison with the arrangement described in U.S. 20 Patent application US 2001/0043642. This is however at the price of a greater complexity due to the reconstruction of the data signal and the evaluation of the quality indicators necessary for the subsequent combination task.

25 Another solution that exploits both a pilot signal and a data signal is described in U.S. Patent application US 2002/0122471. In the arrangement disclosed in this last cited document estimation is improved by using the data carried by different 30 channels rather than in the pilot channel. By enabling the formation of channel estimates based on the data channel, the method is able to achieve superior channel demodulation performance. A channel estimate combiner is used to achieve a weighted average of the pilot and 35 the data channel estimates, each scaled according to

specific scaling factor values. The scaling factor values are provided to the combiner by a control processor, which evaluates these values based on the data channel quality metric. The main drawback of this
5 solution lies in its intrinsic complexity.

Object and summary of the invention

The prior art arrangements described in the foregoing are thus affected by essential drawbacks, such as an incomplete exploitation of the two channels
10 (pilot and data), or an extremely complex structure that makes hardware implementation rather difficult.

The object of the present invention is thus to provide an improved arrangement dispensing with those drawbacks.

15 According to the present invention, that object is achieved by means of a method having the features set forth in the claims that follows. The invention also relates to a corresponding system (adapted to be included e.g. in a CDMA receiver) as well as a related
20 computer program product loadable in the memory of at least one computer and including software code portions for performing the steps of the method of the invention when the product is run on at least one computer.

Preferred embodiments of the arrangement described
25 herein comprise a method and a device for the estimation of the transfer function of a transmission channel having both a pilot signal and a data signal which contains a dedicated pilot field. The preferred embodiments in question are based on a low complexity
30 arrangement, for the estimation of the transfer function of a transmission channel. These embodiments are particularly suitable for use in connection with transmission paths supplied with a pilot signal and a data signal containing a pilot field as is e.g. the

case of the transmission path toward a mobile terminal, called "down-link", in a mobile communication system.

A preferred embodiment of the arrangement described herein achieves an automatic maximum ratio 5 combination between the two above signals without introducing any processing overhead.

Brief description of the enclosed drawings

The invention will now be described, by way of example only, by referring to the enclosed figures of 10 drawing, wherein:

Figures 1 to 6, related to the prior art, have been already described in the foregoing;

Figure 7 is a functional block diagram of apparatus exemplary of the arrangement described 15 herein;

Figures 8 and 9 are functional block diagrams of the pilot signal estimation unit and the data signal estimation unit, respectively, included in the apparatus of figure 7;

20 Figure 10 is a performance graph, expressed in terms of raw BER at the output of a mobile terminal rake receiver, showing the performance achieved by means of the arrangement described herein; and

Figure 11 is an example of a rate adaptation unit 25 procedure in three different slot formats adopted in the arrangement described herein.

Description of preferred embodiments of the invention

An exemplary embodiment of the invention will now 30 be described in an application that is specific but not limited to the estimation of the propagation channel in a W-CDMA system such as the UMTS downlink path.

The channel estimation arrangement described herein is adapted to derive an estimate of the propagation channel C between a base station 1 and a mobile terminal 2 (see figure 1) when considering e.g.

5 a UMTS system operating in FDD mode in its downlink path. If transmit diversity is employed by using two transmit antennas in the base station 1, both such fading channels will be estimated in the mobile terminal 2.

10 Since a coherent reception scheme is employed, channel estimation is achieved making use of known pilot symbols that are transmitted along with the data symbols. When considering the specific case of the UMTS-FDD system, the estimation operation exploits both

15 the Dedicated Physical CHannel (DPCH) and the Primary Common Pilot CHannel (P-CPICH). The downlink channel estimation described herein is simultaneously carried out on both the above channels as shown in figure 7.

20 The respective "fingers" in the receiver are designated 16 (data), and 17 (pilot), respectively.

Within the downlink DPCH dedicated data generated at higher layers are transmitted in time multiplex with control information generated at the physical layer. Hence a certain number of known pilot bits is

25 transmitted. The P-CPICH is a fixed rate downlink physical channel, with a fixed spreading factor equal to 256, which carries a pre-defined sequence.

On the DPCH, the spreading factor is not fixed, and a different number of estimates, evaluated on a

30 different reference time period, are derived according to the specific slot format used, by exploiting the data signal estimation unit 18.

Conversely, the P-CPICH is a fixed rate channel; it is thus possible to extract therefrom a fixed number

of estimates per slot, each of which is evaluated on a basic P-CPICH reference time period by exploiting the pilot signal estimation unit 19. A basic estimation reference time T is chosen and the P-CPICH channel 5 estimates are eventually mapped on this time basis.

Referring to figure 8, that details the internal structure of the estimation unit 19, it is possible to increase the estimation accuracy carried out on the pilot signal estimator proper, designated 21, by 10 exploiting an optional moving average block 22. This optional block performs a moving average on a certain number of consecutive channel estimates of the P-CPICH that have been derived by means of the pilot signal estimator 21. Each channel estimate (present) is 15 averaged with the previous (past) and with the subsequent ones (future). A rate adaptation unit 27 may be possibly cascaded to the block 22 for reasons that will become clear in the following.

Referring to figure 9, the data signal channel 20 estimates are referred to a basic estimation reference time T that in the following will be assumed to be equal to the basic (respective) DPCH reference time period. Those of skill in the art will promptly appreciate that such an assumption is being made 25 primarily for the sake of simplicity of illustration and is in no way a mandatory choice.

If the basic DPCH reference time period is different from the basic estimation reference time, the rate adaptation unit 23 can be possibly used in the 30 unit 18 downstream of the data signal estimator 24. This unit maps the estimates derived from the data signal on the basic estimation reference time. In that way also the values of the channel estimates obtained on the data signal will be referred to the same basic 35 estimation reference time.

Since on the DPCH the channel coefficients can be estimated only in correspondence of the pilot symbols, the channel coefficients cannot be estimated continuously over one slot. In order to estimate the 5 channel coefficients in the remaining part of every slot, after the rate adaptation unit 23, interpolation is required.

A preferred arrangement uses a kind of interpolation operating between the channel estimates 10 obtained from the pilot field within the current slot L and the channel estimates obtained from the pilot field of the previous slot L-1. An interpolator module 25 performs an interpolation (such as e.g. a linear interpolation or an interpolation based on Lagrange 15 polynomials) thus bringing the number of estimates per slot evaluated on the DPCH equal to those evaluated on the P-CPICH.

A fixed number of estimates will be drawn out on both channels, whatever slot format is being used. 20 These estimates are evaluated in such a way to be proportional to their own power level and hence, implicitly, to their own reliability. It follows that if these estimates are summed together (and this is feasible since they are both referred to the same basic 25 reference time period) a maximum ratio combining will be automatically achieved, without the need of any further processing and hence any increase in the system complexity.

Moreover, when adopting this arrangement, a 30 notable enhancement in system performance is achieved in comparison to the prior art, as for example when exploiting only one of the channels as in U.S. Patent application US2001/0043642 referred to in the foregoing. This improvement is obtained without any 35 need of quality indicators and/or further processing

which would inevitably increase system complexity as is the case of the arrangements shown e.g. in U.S. Patent applications US2002/0186677 or US2002/0122471.

An enhancement in system performance (expressed in terms of raw BER measured at the output of the inner modem) is achieved for all UMTS conformance test services when using the combination of both the two channel estimates as shown in figure 10. Specifically, in the graph of figure 10 the curves designated A and B refer to the performance of systems where channel estimation is performed on the basis of the DPCH and the P-CPICH signal, respectively. The curve designated C refers to the arrangement described herein.

More in detail, the arrangement described herein exploits both the Dedicated Physical CHannel (DPCH) and the Primary Common Pilot CHannel (P-CPICH): the channel estimates thus obtained are fed to an automatic maximum ratio combiner that exploits both such estimates. If transmit diversity is employed by using two transmit antennas in the base station, both such fading channels are estimated in the mobile terminal rake receiver.

In the arrangement described herein two different signals are exploited independently to derive the channel estimates. These estimates are easily processed in order to refer them to the same basic estimation reference time and are made proportional to their own power levels and hence their own degrees of reliability. Once this is done, the estimates coming from the two different signals are summed together, yielding an overall channel estimate that is more accurate than the single estimates alone.

Before proper channel estimation can be achieved, the first tasks to be accomplished are the operations performed within the rake receiver finger as shown in

figure 2. Within the fingers 4 the operations of descrambling, despreading, integrate-and-dump are performed in order to separate the different transmitted channels at the receiving end.

5 The Primary Common Pilot Channel (P-CPICH) of the UMTS-FDD system is a fixed rate downlink physical channel with a spreading factor equal to 256 that carries a pre-defined sequence. The frame structure of the downlink CPICH is shown in figure 4a. When
10 employing transmit diversity, the pre-defined symbol sequence of the CPICH is different for the two antennas as shown in figure 4b.

15 It is possible to estimate the channel characteristics by exploiting this known pre-defined sequence.

20 Referring again to figure 7, after the descrambling, despreading and integrate-and-dump operations have been carried out within the pilot finger 17, the symbols are fed to the pilot signal estimation unit 19. This block knows the exact pilot sequences that have been actually transmitted on the pilot signal.

25 The overall pilot signal estimation unit 19 is shown in figure 8.

30 The decoding strategy is the following: the symbols received from the pilot finger 17 are decoded over a certain time epoch, i.e. the P-CPICH decoding time epoch, by correlating them with the stored reference pilot symbols within the pilot signal estimator 21.

For example, if transmit diversity is active, the P-CPICH decoding time epoch of the P-CPICH signal of the UMTS-FDD system is equal to 512 chips while, if transmit diversity is not active, the P-CPICH decoding

time epoch of the P-CPICH signal of the UMTS-FDD system is equal to 256 chips.

In the following a "basic estimation reference time" T is chosen and represents the time basis on which the estimates coming from the two different signals will always be mapped, in order to ensure a true automatic maximum ratio combination of the same.

The pilot channel estimates thus obtained are returned at the output and eventually fed to the optional moving average unit 22. This optional operation is able to increase the estimation accuracy of the pilot signal estimates by performing a moving average on a certain number of consecutive channel estimates that have been derived by means of the pilot signal estimator 21. Each channel estimate (present) is averaged with a certain number of previous (past) and subsequent ones (future). If the block 22 is introduced in the system, the moving average operation introduces an additional latency in the system, but on the other hand increases the estimation accuracy and hence improves the system performance.

The rate adaptation block 27 of figure 8 is an optional block. When present, it is intended to guarantee that the overall pilot signal estimation unit 19 always returns a fixed number of estimates per slot, each referred to the basic estimation reference time. This is done by splitting or integrating different subsequent estimates, in order to reach the basic estimation reference time duration. If the block 27 is dispensed with, the system is able to work only in the specific case where the channel estimates from the pilot signal and the data signal are already based on the same time reference and this time reference is equal to the selected basic estimation reference time.

For example, due to the presence of transmit diversity, the pilot signal estimator 21 may return fewer estimates per slot, each evaluated on a larger decoding time epoch. In that case, each significant 5 value is split within the pilot signal rate adaptation block 27 in order to be referred, after the splitting, to the basic estimation reference time. The pilot channel estimates, which have been eventually averaged within block 22 and rate adapted within block 27, are 10 fed to the adder 26. The overall cascade of blocks 18, 15 and 26 makes up the automatic MRC combiner 20.

Within the downlink Dedicated Physical Channel (DPCH) of the UMTS-FDD system dedicated data generated at higher layers is transmitted in time multiplex with 15 control information generated at the physical layer. The frame structure of the downlink DPCH is shown in figure 3.

Each frame of length 10 ms is split into 15 slots, 20 each of length $T_{slot} = 2560$ chips, corresponding to one power-control period. Within the aforementioned control information, a certain number of known pilot bits are transmitted (besides TPC commands and an optional TFCI). These pilots are used for the estimation of the transmission channel characteristics. According to the 25 different slot format that is adopted, different pilot bit patterns are used.

Referring to figure 7, after the descrambling, despreading and integrate-and-dump operations have been carried out within the data finger 16, the next task is 30 to extract the time-multiplexed pilot symbols from the entire slot structure. This is easily done since the data signal frame structure is known at the receiver.

After extraction from the received sequence, the pilot field symbols are fed to the data signal

estimation unit 18. This block knows the exact pilot sequences that have been actually transmitted on the data signal. Exploiting the knowledge of the pilot bits, the channel phases can be estimated.

5 The overall data signal estimation unit 18 is shown in figure 9. After extraction from the received sequence, the pilot field symbols are fed to the first block of the data signal estimation unit 18, named data signal estimator 24. This block has knowledge of the 10 pilot sequence that has been actually transmitted on the data signal by the base station 1. If transmit diversity is used in the base station 1, the data signal estimator 24 has knowledge of both the antenna patterns. Exploiting the knowledge of both these pilot 15 patterns, the channel phases will be estimated.

The decoding strategy is the following: the symbols received from the data finger 16 are decoded over a certain time epoch, i.e. the DPCH decoding time epoch, by correlating them with the stored reference 20 pilot symbols within the data signal estimator 24. In the specific case of the UMTS-FDD system, when transmit diversity is active the DPCH decoding time epoch is equal to the entire pilot field, while when transmit diversity is not active, the DPCH decoding time epoch 25 is equal to one DPCH pilot symbol duration. The data channel estimates thus obtained are returned at the output and fed to the rate adaptation unit 23.

The overall data signal estimation unit 18 is implemented in such a way that it always returns a 30 number of estimates per slot equal to the number of estimates per slot derived from the pilot signal estimation unit 19. Each of these estimates is evaluated on the basic estimation reference time.

Referring to figure 9, this is achieved by first 35 exploiting the rate adaptation unit 23 that maps the

data signal channel estimates on the basic estimation reference time (no matter what spreading factor is used on the data signal) and then, in the subsequent interpolator unit 25, by performing interpolation in 5 the remaining part of the slot in order to reach the fixed number of estimates per slot.

The rate adaptation unit 23 may operate in several different manners, according to the different operations that must be done to map the data signal 10 estimates on the basic estimation reference time. The working modalities of the rate adaptation unit 23 basically depend on two quantities whose value must be pre-analyzed:

- the ratio of the data signal overall pilot field 15 to the basic estimation reference time, henceforth referred to as "kappa", and

- the ratio of the data signal spreading factor value to the basic reference spreading factor value, henceforth referred to as "gamma".

20 The basic reference spreading factor is defined as the number of chips within the basic estimation reference time T.

The rate adaptation algorithm implemented in module 25 works on a slot basis and consists of the following steps.

First of all the value of kappa must be checked.

If $\kappa \leq 1$, the length of the data signal pilot field is smaller (i.e. shorter) than or equal to the basic estimation reference time T. In this case, 30 integration is carried out on the data signal channel estimates in order to be mapped to the basic estimation reference time. The so-obtained integrated channel estimate is returned at the output. An example of this case is shown in figure 11a.

If $\kappa > 1$, the length of the data signal pilot field is greater (i.e. longer) than the basic estimation reference time T . In this case the estimates are split, converting them to the basic estimation reference time basis. Two different situations may occur in this case (according to the value of γ). At this point the value of γ must be checked.

If $\gamma \geq 1$, the single generic data signal channel estimate has been evaluated over a DPCH decoding time epoch that is larger than or equal to the basic estimation reference time T . It should hence be split to a basic estimation reference time basis. The so-obtained split channel estimates are returned at the output. An example of this case is shown in figure 11b.

If $\gamma < 1$, the single generic data signal channel estimate has been evaluated over a DPCH decoding time epoch that is smaller than the basic estimation reference time T . It should hence be integrated on a basic estimation reference time basis. The so-obtained integrated channel estimates are returned at the output. An example of this case is shown in figure 11c.

It will be appreciated that the same processing steps exemplified above in connection with the data signal pilot field can be performed also for the pilot signal if the basic CPICH reference time period is different from the basic estimation reference time T .

The rate adaptation unit 23 works also in the presence of transmit diversity.

When referring, as in figure 3, to a data signal containing only a dedicated pilot field, time-multiplexed with the information data, for the channel estimation task, it is clear that the channel coefficients can be estimated only in correspondence of the pilot field. It follows that it is not possible to

estimate the channel coefficients continuously over one slot.

In order to estimate the channel coefficients in the remaining part of every slot, after the optional 5 rate adaptation unit 23 shown in figure 9, interpolation is required. The basic idea consists in using a kind of interpolation operating between the channel estimates obtained from the pilot field within the current slot and the channel estimates obtained 10 from the pilot field of the previous slot. The interpolator 25 performs an interpolation, by means of a given algorithm of any known type, in order to evaluate the missing channel estimates, each referred to the basic estimation reference time, thus bringing 15 the number of estimates per slot up to the fixed value. In such a way the number of estimates per slot evaluated on the data signal is equal to the number of estimates per slot evaluated on the pilot signal.

Referring once again to figure 7, after the 20 estimation operations 18 and 19 have been carried out both on the data signal and on the pilot signal, the adder 26 receives the same number of estimates per slot, each evaluated on the basic estimation reference time, from both these estimation units. By simply 25 summing, on a basic estimation reference time basis, the channel estimates together brings to a maximum ratio combination of the same. This is achieved automatically, without the need of further processing and/or without increasing in the system complexity, 30 since the amplitudes of the estimates and thus their reliability, are proportional to the spreading factor and to the power of each received channel estimate.

It is thus evident that, the basic principles of the invention remaining the same, the details and 35 embodiments may widely vary with respect to what has

been described and illustrated purely by way of example, without departing from the scope of the presented invention as defined in the annexed claims.

This applies i.a. to the possibility of making the
5 sum performed at the summation node 26 of figure 7 a weighted sum of the estimates derived from the pilot signal estimation unit 19 and the data signal estimation unit 18, and the possibility of dispensing with the step of mapping the channel estimates derived
10 from the data signal and/or the pilot signal over the basic estimation reference time.